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Abstract

One of the most interesting and ongoing problems in Executive Information Systems research is, "What does an executive do with the results?" At the personal level, people attempt to make sense out of a minimal amount of information by forming prototypes and constructing scenarios. At the organizational level, we often have too much information to form realistic models in addition to a multiplicity of different objects to which the information can be applied. This paper initiates a relevant development process by describing how information can be combined and applied to Executive Information Systems. Dempster's Rule of Combination is introduced and technical methods for assessment and consensus are covered. Examples are given for voting systems and the elicitation of expert opinion

Keywords: Dempster's Rule, Dempster-Shafer Theory, Combination of Evidence, Frame of Discernment

Introduction

One of the most interesting and ongoing problems in Executive Information Systems research is, "What does an executive do with the results?" At the personal level, people attempt to make sense out of a minimal amount of information by forming prototypes and constructing scenarios. At the organizational level, we often have too much information to form realistic models in addition to a multiplicity of different objects to which the information can be applied. This paper initiates a relevant development process by describing how information can be combined and applied to Executive Information Systems.

Operational Context

In order to alleviate the unfortunate problem of having too much information, it would seem prudent to delineate the cognitive process involved that could be incorporated into an information system. Accordingly, five *major* steps are involved: selection, mapping to the problem domain, combination of information, mapping to the output domain, and the decision process, suggested by Figure 1. *Selection* is merely the choice of information that is relevant to a particular situation. Typical examples would be results from data mining, a fundamental analysis report, and a what-if spreadsheet. In a decision context, information is evidence to which meaning must be ascribed. This step reflects the "advisor paradigm" and is referred to as *Mapping to the Problem Domain*. The third step is the *Combination of Information*, which is the key element in the process and the primary subject of this paper. The next step is a *Mapping to the Decision Domain* that delineates the decision maker's options. The last step is the *Decision Process*, which may or may not be automated.

Two of the processes deserve special consideration: Selection and Mapping to the Problem Domain. Selection refers to the identification of the relevant indicators and mapping refers to what the indicators mean to the current problem. Collectively, the cognitive processes reflect a *knowledge-based modality* for Executive Information Systems.

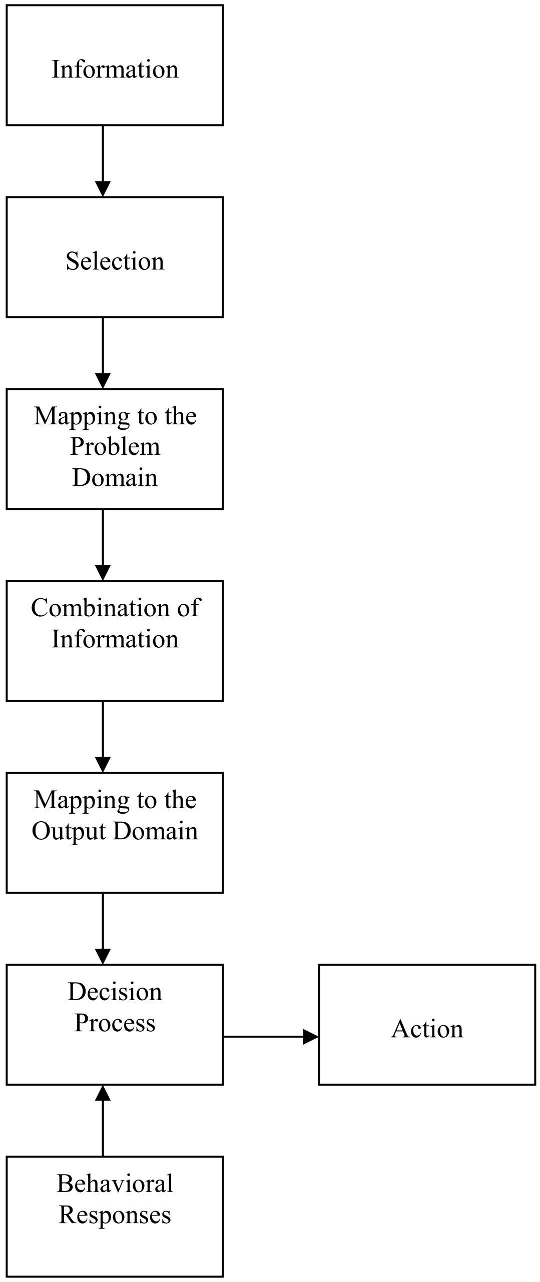

Figure 1. Cognitive Model of the Advisor Paradigm

Organization and Analysis

Within a given problem domain, the set of mutually exclusive and collectively exhaustive possibilities is referred to as the *frame of discernment* (known simply as a *frame*). Three examples of frames are:

V = {Bush, Kerry, Nader}
E = {Up, Unchanged, Down}

In general, a frame is a means of representing the possibilities under consideration.

Clearly, the elements in a frame are in fact propositions that can be interpreted as events or states. Thus, if component s_i of system S over domain V were associated with the symbol "Bush," then that state is equivalent to the proposition, "The true value of V for component s_i is *Bush*," or in ordinary language, "s_i prefers *Bush*."

Accordingly, the set S of propositions S_i,

$$S = \{S_1, S_2, \ldots, S_n\}$$

represents the collection of possibilities in a problem domain.

Uncertainty

Prior to an agreed point in time (□), we obviously do not know the state of the system under analysis or its possibilities with any degree of certainty. The expectation that a part of the system will be in a particular state at time t is denoted by a real number $p(S_i)$ associated with each of the propositions in the frame S = $\{S_i\}$, i=1,2,…,n, such that

$$0 \le p(S_i) \le 1$$

and

$$\sum_{i=1}^{n} p(S_i) = 1$$

This is simply the addition rule for mutually exclusive events.

Basic Probability Assignment

The basis of assessment is the frame of discernment (Θ), introduced previously. Accordingly, a knowledge source may assign a numerical measure to each distinct element of Θ, which is equivalent to assigning a measure of belief to the corresponding proposition. The numerical measure should be regarded as a basic probability assignment. Theoretically, a measure of belief may also be assigned to a subset of Θ or to Θ itself. In the form of analysis, covered here, probability assignments are made only to individual elements of Θ, permitting conflicting, as well as confirmatory, evidence from multiple source or agents to be combined.

A knowledge source apportions a unit of belief to each element of Θ. This belief can be regarded as a mass committed to the set of propositions and represents a judgment as to the strength of the evidence supporting that position. When viewed in this manner, evidence focuses on the set corresponding to the propositions; this set is called a *view*. For example, consider the frame of discernment *V* given previously

V = {Bush, Kerry, Nader}

In a voting context, a "party" view over the frame V would exist as

Party = {{Bush},0.6},{{Kerry},0.3},{{Nader},0.1}}

Accordingly, this view could be interpreted as the following: *Through political party affiliation, the principal would be expected to vote for Bush with probability 0.6, Kerry with probability 0.3, and Nader with probability 0.1.*

The notion of combining views is a practical approach to the assessment of evidence. An analyst obtains information from a knowledge source, and it leads to an immediate conclusion – not with certainty, but with a certain level of belief. This is a normal straightforward means of handling human affairs and is precisely what people do. Then when additional information comes in, the various pieces of evidence are combined to obtain a composite picture of the situation.

Combination of Evidence

A method of combining evidence is known as Dempster's rule of combination (Dempster, 1967). Evidence would normally be combined when it is obtained from two different observations, each with the same frame of discernment. The combination rule computes a new view reflecting the scope of the combined evidence.

If m_1 and m_2 denote two probability assignments, then their combination is denoted by $m_1 \oplus m_2$ and is called their *orthogonal sum*. The combination $m_1 \oplus m_2$ is computed from m_1 and m_2 by considering all products of the form $m_1(X) \bullet m_2(Y)$, where X and Y range over the elements of Θ; $m_1(X) \bullet m_2(Y)$ is the set intersection of X and Y combined with the product of the corresponding probabilities.

For example, consider the frame of discernment

Θ = {healthy, tests, sick}

and views A and B, based on two different observation over the same frame:

A = {{healthy},0.6},{{tests},0.3},{{sick},0.1}}
B = {{healthy},0.4},{{tests},0.4},{{sick},0.2}}

The combination rule is depicted via the following tableau:

	A		
m_2 \ m_1	{healthy} 0.6	{tests} 0.3	{sick} 0.1
B			
{healthy} 0.4	{healthy} 0.24	{Ø} 0.12	{Ø} 0.04
{tests} 0.4	{Ø} 0.24	{tests} 0.12	{Ø} 0.04
{sick} 0.2	{Ø} 0.12	{Ø} 0.06	{sick} 0.02

The entries are then combined as follows:

$m_1 \oplus m_2(\{\text{healthy}\}) = 0.24$
$m_1 \oplus m_2(\{\text{tests}\}) = 0.12$
$m_1 \oplus m_2(\{\text{sick}\}) = 0.02$
$m_1 \oplus m_2(\{\text{Ø}\}) = 0.62$

Thus, for $A_i \cap B_j = A$ and $m_1 \oplus m_2 = m$, the combination rule is defined mathematically as:

$$m(A) = \sum_{A_i \cap B_j = A} m_1(A_i) \bullet m_2(B_j) / (1 - \sum_{A_i \cap B_j = \emptyset} m_1(A_i) \bullet m_2(B_j))$$

The denominator reflects a normalization process to insure that the pooled values sum to 1. So, in this instance, the normalization process yields the combination

A⊕B = {{healthy},0.63},{{tests},0.32},{{sick},0.05}}

after dividing the combined assessment by 0.38. Because the problem is well-structured, the representation can be simplified as

A⊕B = {0.63,0.32,0.05}

For views A={A_1,A_2,…,A_n} and B={B_1,B_2,…,B_n}, the combination rule can be simplified as

$$A \oplus B = \{A_1 \times B_1/k, A_2 \times B_2/k, \ldots, A_n \times B_n/k\}$$

$$\text{where } k = \sum_{i=1}^{n} A_i \times B_i$$

Applications

Two applications of the preceding concepts are considered: a voting system and the elicitation of expert opinion.

Voting Systems

Consider a system in which a decision maker is required to vote on a well-structured issue, such as the selection of a candidate. Let the candidates be *Roberts*, *Richards*, and *Williams*. Assume further that the voter is influenced by the influential groups of *Party*, *Cause*, and *Lobby* to cast a vote in their best interests. In a real sense, the voter is being pulled in three directions.

Clearly, the frame of discernment is {Roberts,Richards,Williams} and since the problem is well-structured, the view may be summarized as follows:

Party = {0.6,0.3,0.1}
Cause = {0.4,0.2,0.4}
Lobby = {0.4,0.5,0.1}

The information should be interpreted from a probabilistic perspective. For example, based on party affiliation, the voter will choose *Roberts* with a 0.6 probability, *Richards* with a 0.3 probability, and *Williams* with a 0.1 probability. Table 1 summarizes the application of Dempster's rule of combination to this problem. First, *Party* is combined with *Cause* and then the result is combined with *Lobby* to obtain a composite picture of the result when views are fused. In general, the evidence is complementary and this fact is reflected in the final probability of 0.735 that is computed for "Roberts."

Table 1. Application of Dempster's Rule to the Voting System

Support Function	bpa
Party	{0.6,0.3,0.1}
Cause	{0.4,0.2,0.4}
Lobby	{0.4,0.5,0.1}
Party⊕Cause (=K)	{0.706,0.176,0.118}
K⊕Lobby	{0.739,0.230,0.031}

Elicitation of Expert Opinion

Typically, experts do not agree, especially when system failure is concerned. Typical examples might be the crash of an expensive fighter aircraft or the collapse of a building. Consider a situation wherein the frame of discernment is $\{A,B,C\}$ reflecting that the failure could be caused by Component A, Component B, or Component C. Expert #1 believes the failure is due to Component A with probability 0.75, Component B with probability 0.15, or Component C with probability 0.10. Expert #2 believes the failure is due to Component A with probability 0.30, Component B with probability 0.20 or Component C with probability 0.50. The views are:

Expert #1 = {0.75,0.15,0.10}
Expert #2 = {0.30,0.20,0.50}

Table 2 summarizes the application of Dempster's rule of combination to this problem. The opinion of the experts is summarized and reflects the differing opinions.

Table 2. Elicitation of Expert Opinion

Support Function	bpa
Expert #1 (=X)	{0.75,0.15,0.10}
Expert #2 (=Y)	{0.30,0.20,0.50}
X⊕Y	{0.738,0.098,0.164}

The strong opinion of Expert #1 in favor of Component A has a major influence on the combined assessment.

Output Mapping

Once you have combined the information and have a probability assessment of the problem domain, the next step is to map the results to the decision domain. This process reflects a elementary if-then analysis from probability levels to decision scripts.

Summary

The paper introduces the concept of assessment in a decision –making context appropriate to Executive Information Systems. Clearly assessment is the key element in the associated set of cognitive processes. The relationship between the combination of evidence and differing views is explored and examples from voting systems and the elicitation of expert opinion are given.

Reference

Dempster, A.P. (1967), Upper and Lower Probabilities Induced by a Multivalued Mapping, *The Annals of Statistics* 28:325-339.